APPENDIX B

SOIL TEST METHODS

Soil testing can be divided into three general categories: in situ testing, laboratory testing, and soil classification. In situ tests are those conducted in the field on a soil while it is still in the ground. Laboratory testing involves extracting a sample of soil, transporting it to either a field or office laboratory, and manipulating it in some way so as to acquire information about the deposit from which it came. Soil classification is the determination of various physical properties which can be used to evaluate the uniformity of a depositand to provide general correlations with engineering properties.

The-most important soil tests for trench and shoring work are those used to determine soil shear strength. Some of the more significant tests used for soil classification and the determination of shear strength parameters are listed below. The applicable American Society for Testing and Materials (ASTM) test designation is shown in parenthesis.

IN SITU TESTS

FIELD VANE SHEAR TEST (ASTM D2573)

The vane shear test consists of pushing a four bladed vane into undistributed soil at the bottom of a bore hole and rotating it from the surface to determine the torsional force required to cause a cylindrical volume of soil to be sheared by the vane. The torsional force is then related to a undrained shear strength (S_u) using a conversion factor which depends on the dimensions and shape of the vane,

To assure undrained conditions the soil in which this test is conducted must have low permeability. As such, this test is used primarily in fine grained soils. In addition, the soil should be free of gravel or large shell particles which would influence the test results.

This test attempts to provide a direct measurement of S_u and is therefore preferred to an estimation of q_u from the standard penetration test.

A hand held version of the vane shear test uses a device known as the torvane on samples recovered from a test boring. The torvane is one inch in diameter and has blades 0.2 inch long. Undrained shear strength is measured by inserting the torvane into the soil sample andtwisting. Undrained shear strength is indicated by a dial mounted on-the handle. The torvane test does not have an ASTM designation.

CONE PENETRATION TEST (ASTM D3441)

The cone penetration test (CPT) consists of pushing a conically tipped, cylindrical probe into the ground at a slow rate. The probe is instrumented with strain gages used to measure resisting force against the tip (10 cm^2 cross-sectional area) and along the side (15O cm^2 area) while the probe is advancing downward. A computer is typically used to control the advance of the probe, acquisition and recording of data. As such, many readings can be obtained and a nearly continuous record of subsurface information collected.

Relationships exist which correlate subsurface resistance data collected with this instrument to: soil description; relative density for granular soils; and undrained shear strength(SU) for fine grained soils.

Because this probe is advanced slowly, under so called quasi-static loading, estimation of s_u made to using CPT data is preferable to estimation of q_u from the Standard Penetration Test where the sampler is advanced under dynamic loading and unknown damping forces may influence the data in soils with low permeability.

STANDARD PENETRATION TEST (ASTM D1588)

The Standard Penetration Test (SPT) consists of driving a 1.4 inch I.D. (2.0 inch O.D.) sampler 18 inches into the bottom of a bore hole using a 140 hammer dropped 30 inches. The number of blows required to drive the sampler the last 12 inches is defined as the SPT blow count (N).

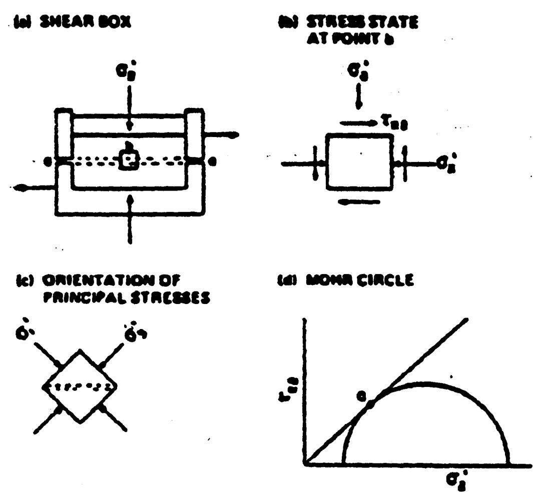
In addition to N, this test provides a means of retrieving soil samples for visual description or laboratory tests appropriate for highly disturbed soil. Empirical relationships exist which can be used to correlate N to relative density of granular soils and unconfined compressive strength (q_u) for fine grained soils.

APPENDIX B

LABORATORY TESTS

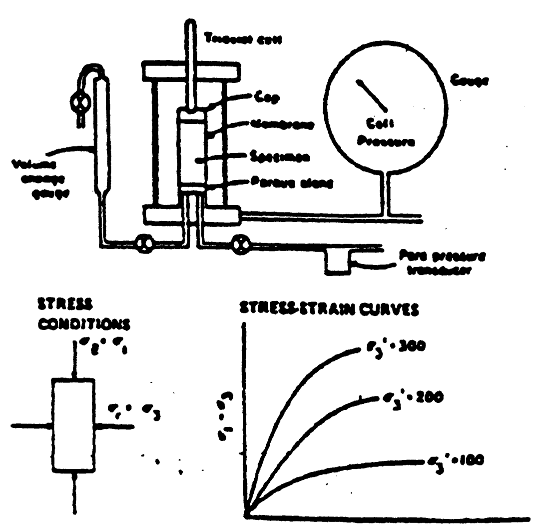
DIRECT SHEAR TEST (ASTM D3080)

In a direct shear test, the soil is placed in a split shear box and stressed to failure by moving one part of the container relative to the other. The specimen is subjected to a normal force and a horizontal shear force. The normal force is kept constant throughout the test and the shear force is increased usually at constant rate of strain to cause the specimen to shear along a predetermined horizontal plane. If it is assumed that the horizontal plane is equivalent to the failure plane for the soil, then the friction angle can be calculated from the results of a series of tests performed at various normal stresses.



The direct shear test offers the easiest way to measure the friction angle of a sand or other dry soil. It is not useful for testing soils containing water unless they are free draining and-have a very high permeability, because it is difficult to control the drainage and thus volume changes during testing. For this reason, the direct shear tests should be used with caution in determining the undrained shear strength of cohesive soils.

TRIAXIAL COMPRESSION TEST (ASTM D2850)



The triaxial test is most versatile test available to determine the stress-strainproperties of soil. For the most common triaxial test (the triaxial compression test) a cylindrical specimen is sealed in a rubber membrane and placed in a cell and subjected to a uniform fluid pressure in the horizontal and vertical directions. A vertical load is applied axially to the specimen increasing the axial stress until the specimen fails. Under these conditions, the axial stress is the major principal stress,

σ_1, and the intermediate and minor principal stresses, σ_2, and σ_3 respectively, are equal to the cell pressure. The increment of axial stress, $\sigma_1 - \sigma_3$, is referred to as the deviator stress or principal stress difference.

Drainage of water from the specimen is controlled by connections to the bottom cap. Change in sample volume is measured if drainage is allowed. Alternatively, pore water pressures may be measured if no drainage is allowed. Triaxial tests are generally classified as to one of three conditions of drainage during application of the cell pressure and loading. The three drainage conditions for testing are the (UU), (CU), and (CD) referenced below.

Unconsolidated-Undrained (UU)

No drainage is allowed during application of the cell pressure or confining stress and no drainage is allowed during application of the deviator stress. This test is generally performed on undisturbed saturated samples of fine grained soils (clay, silt and peat) to measure the in situ undrained shear strength ($\phi = 0$ analysis). For soils which exhibit peak stress-strain characteristics, the failure stress is taken as the maximum deviator stress ($\sigma_1 - \sigma_3$) measured during the test. For soils which exhibit an increasing deviator stress with strain, the failure stress. is generally taken as the deviator stress at a strain equal to 20 percent. Theundrained shear strength, s_u is taken as half the deviator stress or:

$$s_u = (\sigma_1 - \sigma_3)/2$$

The in situ undrained shear strength is applicable to conditions in which construction occurs rapidly enough so that no drainage and hence, no dissipation of excess pore pressures occur during construction. Examples of typical situations in which the in situ undrained shear strength would govern stability include construction of embankments on clay deposits or rapid loading of footings on clay.

Unconsolidated-undrained tests are also performed on samples of partially saturated cohesive soils. The principal application of tests on partially saturated samples is to earth-fill materials which are compacted under specified conditions of water content and density. It also applies to undisturbed samples of partially saturated and to samples recovered from existing fills. However, because the tests are performed on partially saturated soil, the deviator stress at failure will increase with continuing pressure.

The failure envelope expressed in terms of total stress is non-linear and values of C and ϕ can be reported only for specific ranges of confining pressures.

Consolidated-Undrained (CU)

Drainage is allowed during application of the confining stress so that the specimen is fully consolidated under this stress. No drainage is permitted during application of the deviator stress. This test is performed on undisturbed samples of cohesive soil, on reconstituted specimens of cohesionless soil and, in some instances, on undisturbed samples of cohesionless soils which have developed some apparent cohesion resulting from partial drainage.

Generally, the specimen is allowed to consolidate under a confining stress of known magnitude and is then failed under undrained conditions by applying an axial load. The volume change that occurs during consolidation should be measured. The results of CU tests, in terms of total stress or undrained shear strength, must be applied with caution because of uncertainties in the effects of stress history and stress system (isotropic consolidation) on the magnitude of strength increase with consolidation.

If the pore pressure is measured during the test, the results can be expressed in terms of effective stress, **c' and ϕ'.**

The principal application of results of CU tests on cohesive soils is to the situation where additional load is rapidly applied to soil that has been consolidated under previous loading (shear stresses). The principal application to cohesionless soils is to evaluate the stress-strain properties as a function of effective confining stress.

Consolidated-Drained (CD)

Drainage is permitted both during application of the confining stress and the deviator stress, such that the specimen is fully consolidated under the confining stress and no excess pore pressures are developed during testing. Consolidated drained tests are performed on all types of soil samples, including undisturbed, compacted and reconstituted samples.

In a standard test, the specimen is allowed to consolidate under a predetermined confining stress and the specimen is then sheared by increasing the axial load at a sufficiently slow rate to prevent development of excess pore pressure. Since the excess pore pressure is zero, the applied stresses are equal to the effective stresses and the strength parameters, **c' and ϕ'** are obtained directly from the stresses at failure. The volume changes that occur during consolidation and shear should be measured.

The principal application of the results of CD tests on cohesive soils is for the case where either construction will occur at a sufficiently slow rate that no excess pore pressures will develop or sufficient time will have elapsed that all excess pore pressures will have dissipated (i.e. long term conditions).

The principal application to cohesionless soils is to determine the effective friction angle.

UNCONFINED COMPRESSION TEST (ASTM D2166)

The unconfined compression test measures the compressive strength (q_u) of a cylinder of cohesive soil which has no lateral confinement (unconfined). The undrained shear strength (S_u) is normally taken as approximately equal to one-half of the compressive strength. This test can be considered as a special case of the UU triaxial test in which the confining stress is zero.

The test is generally performed on an undisturbed specimen of cohesive soil at its natural water content. Cohesionless soils, such as sands and non-plastic silts and fissured or layered materials, should not be tested unconfined because the shear strength of these types of soils is a function of the in situ confining stress.

A hand held device known as the pocket penetrometer is often used to estimate q_u from samples recovered from a test boring. Basically a spring loaded scale, the pocket penetrometer is used by pushing the 0.25 inch diameter penetrometer rod into a sample. It is calibrated so that an estimate of q_u is indicated on the scale. The pocket penetrometer test does not have an ASTM designation.

SOIL CLASSIFICATION

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX (ASTM D4318)

Liquid and plastic (Atterberg) limits are empirical boundaries which separate the states of fine grained soil. For example, a soil at a very high water content is in a liquid state. As the water content decreases, the soil passes the liquid limit and changes to a plastic state. As the water content decreases further, the soil passes the plastic limit and changes to a semi-solid state.

The liquid limit (LL) is defined as the water content at which a standard groove closes after 25 blows in a liquid limit device. The plastic limit (PL) is the water content at which the soil begins to crumble when rolled into 0.125 inch diameter threads. The thread should break into numerous pieces between 0.125 inch and 0.375 inch long. Plasticity Index (PI) is the difference in the water content between the LL and the PL. This value represents the range of water content over which soil behavior can be characterized as being in a plastic state.

The purpose of the limits is to aid in the classification of fine-grained soils (silts and clays), to evaluate the uniformity of a deposit and to provide some general correlations with engineering properties.

In accordance with the Unified Soil Classification System, a fine-grained soil is classified as to its position on the plasticity chart, TABLE 8. The uniformity of a fine grained soil deposit can be evaluated by plotting the test results of natural water content and Atterberg limits versus depth or elevation.

The liquid and plastic limits are not well correlated with engineering properties that are a function of soil structure or its undisturbed state. However, some general empirical correlations for fine-grained soils have been developed based on index properties, natural water content and Atterberg limits.

CORRELATION OF VARIOUS PROPERTIES:

- Expansion Potential: According to NAVFAC DM7.1-38 and DM7.3-82.
- Consolidation Stress versus Liquidity Index: According to NAVFAC DM7.1-142.
- Coefficient of Consolidation versus Liquid Limit: According to NAVFAC DM7.1-224.

CLASSIFICATION AND FIELD IDENTIFICATION OF SOILS (ASTM D2487 & D2488)

The Unified Soil Classification System (USCS) (ASTM D2487), is based on the identification of soils according to the type and predominance of the constituents considering the following:

- Grain size
- Gradation (shape of grain size distribution curve)
- Plasticity and compressibility

The System divides soils into three major divisions:

- Coarse grained
  (more than 50 percent retained on the No. 200 sieve)
  The smallest size in this category is about the smallest particle size which can be distinguished with the naked eye. Coarse grained soils are classified as to their particle size and shape of the grain size distribution curve.

- Fine grained
  (more than 50 percent passing the No. 200 sieve)
  Fine grained soils are classified as to their position on the plasticity chart shown in TABLE 8.

- Highly organic soils
  These soils are peat or other soils which contain substantial amounts of organic matter. No laboratory criteria exist for the highly organic soils; however, they can generally be identified in the field by their distinctive color and odor and by their spongy feel and fibrous texture.

Details of the System are summarized in TABLE 8. Only particles sized 3 inches or less are considered in USCS. Fragments which are larger than 3 inches are classified as cobbles or, if larger than 8 inches, boulders.

Soils can be USCS classified by simple laboratory procedures. However, with practice and experience, it is possible to accurately identify a soil in the USCS by visual means, some of the techniques used for field description and identification are described in ASTM D2488.

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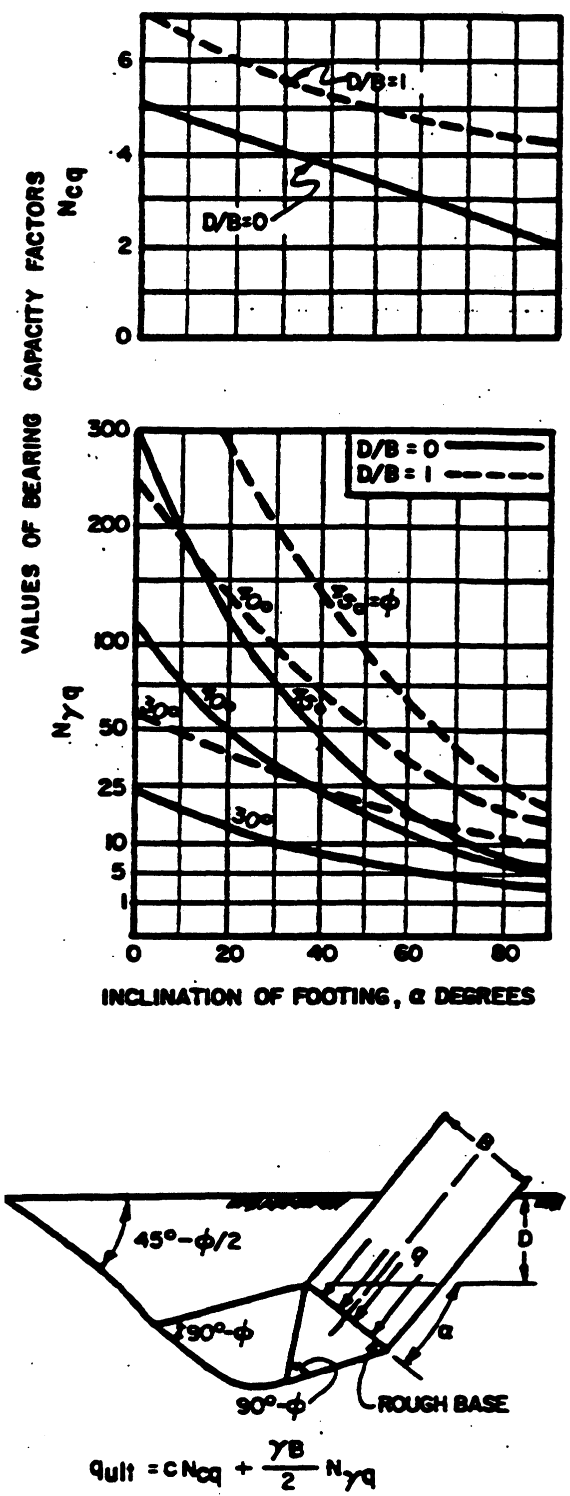
INCLUDED LOAD ON INCLINED FOOTINGS



INCLUDED LOAD ON INCLINED FOOTINGS

Ultimate Bearing Capacity of Continuous Footings with Inclined Load as taken from Department of the Navy (1982) *Foundations and Earth Structures, Design Manual 7.2,* NAVFAC DM-7.2, Naval Facilities Engineering Command